Lower-extremity complications with femoral extracorporeal life support

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ABSTRACT

Objective: Patients undergoing emergency peripheral arteriovenous extracorporeal life support were evaluated for lower-extremity complications on the basis of the ipsilateral limb perfusion strategy.

Methods: In a retrospective review of patients receiving extracorporeal life support (2008-2013), 105 of 250 underwent femoral extracorporeal life support. For ipsilateral lower-extremity perfusion, patients underwent no superficial femoral artery cannulation ($n = 35$), percutaneous superficial femoral artery cannulation ($n = 23$), or open superficial femoral artery cannulation ($n = 47$).

Results: Patients' mean age was 50 ± 16 years, and 63% ($n = 67$) were male. A total of 92 patients (88%) had primary cardiac emergency, and 13 patients (12%) had cardiopulmonary emergency. The 30-day in-hospital mortality was 65% ($n = 68$), with an overall lower-extremity complication rate of 13% ($n = 14$). Lower-extremity complications were highest in the percutaneous superficial femoral artery ($n = 6$, 26%) and no superficial femoral artery ($n = 7$, 20%) groups ($n = 1$ [2%] in open superficial femoral artery group). In 2 group comparisons, the open superficial femoral artery group had significantly lower lower-extremity complications than the no superficial femoral artery ($P = .02$) and percutaneous superficial femoral artery ($P = .004$) groups. There was no difference between the no superficial femoral artery and percutaneous superficial femoral artery groups ($P = .7$). In the no superficial femoral artery group, emergency thromboembolectomy ($n = 2$), fasciotomy ($n = 3$), and emergency superficial femoral artery cannula placement ($n = 2$) were required. In the percutaneous superficial femoral artery group, thromboembolectomy with superficial femoral artery repair ($n = 2$), fasciotomy ($n = 1$), below-knee amputation ($n = 1$), open superficial femoral artery cannula revision ($n = 1$), and loss of distal signals from multiorgan failure ($n = 1$) were noted. In the open superficial femoral artery group, 1 patient had loss of signals from multiorgan failure.

Conclusions: No superficial femoral artery perfusion strategy is associated with a high lower-extremity complication rate. If percutaneous cannulation is performed, then angiographic confirmation of superficial femoral artery run-off is highly recommended. The open superficial femoral artery approach remains a safe alternative to the other strategies. (*J Thorac Cardiovasc Surg* 2016;151:1738-44)

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Central Message

Ipsilateral limb perfusion via SFA cannulation is an important adjunct in patients undergoing peripheral arteriovenous extracorporeal membrane oxygenation.

Perspective

Peripheral arteriovenous extracorporeal membrane oxygenation via femoral cannulation is being increasingly performed, and there are no defined strategies set in place for ipsilateral distal limb perfusion in these patients. In this study, we reviewed our institutional outcomes with 3 different management strategies for limb perfusion and show that expectant monitoring of patients is associated with high limb ischemia.

See Editorial Commentary page 1745.

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Read at the 95th Annual Meeting of The American Association for Thoracic Surgery, Seattle, Washington, April 25-29, 2015.

Received for publication May 28, 2015; revisions received Nov 11, 2015; accepted for publication Nov 15, 2015.

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<http://dx.doi.org/10.1016/j.jtcvs.2015.11.044>

Arteriovenous extracorporeal life support (ECLS) has become an important form of mechanical support in critically ill patients with severe cardiopulmonary compromise and as a

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Abbreviations and Acronyms

ECLS	= extracorporeal life support
ECMO	= extracorporeal membrane oxygenation
ICU	= intensive care unit
PSFA	= percutaneous superficial femoral artery
SFA	= superficial femoral artery

rescue strategy for patients in cardiac arrest.¹⁻⁸ As institutions increasingly use ECLS, the cardiac surgical community will need to assess its indications and applications in a more meticulous and methodical manner. Peripheral ECLS through cannulation of the femoral artery and femoral vein $\pm$ internal jugular vein is the most commonly used modality, compared with central ECLS, which is typically seen in patients postcardiotomy shock.²⁻⁵ Ipsilateral limb ischemia is one of the major complications associated with peripheral ECLS, because the retrograde arterial cannula can cause marked vessel occlusion leading to potentially devastating distal ischemia.⁹⁻¹⁶ Although several groups advocate for various methods of ipsilateral limb perfusion,¹⁷⁻¹⁹ a thorough understanding of the associated complications from different limb perfusion strategies is required. At the Hospital of the University of Pennsylvania, the treatment of ipsilateral limb perfusion has evolved from expectant monitoring to percutaneous or open cut-down with antegrade.

Superficial femoral artery (SFA) cannulation: As the use of ECLS has increased over the past 5 years and patients are being sustained on ECLS for longer periods of time, there is a need for reliable, safe, and sustainable strategy for ipsilateral limb perfusion in these patients. In this study, we assessed whether the type of limb perfusion strategy influenced the rate and severity of ipsilateral limb ischemia in patients with peripheral ECLS.

MATERIALS AND METHODS

Patients

Institutional review board approval was obtained for this retrospective review. From February 2008 to December 2013, 250 patients underwent emergency ECLS at a single institution, of whom 105 (42%) had peripheral ECLS, with common femoral artery and common femoral vein cannulation. Right internal jugular vein drainage cannula and vent for left ventricular decompression were placed as needed. On placement of the common femoral arterial cannula and initiation of ECLS, the decision for ipsilateral limb perfusion strategy was based on the surgeon's preference. Patients were divided into 3 groups by ipsilateral limb perfusion management: no SFA cannulation (no SFA group, $n = 35$, 33%), percutaneous SFA (PSFA) cannulation (PSFA group, $n = 23$, 21%), and groin cut-down with open SFA cannulation (open SFA group, $n = 47$, 45%).

Operative Techniques and Surgical Approach

All ECLS cases were performed on an emergency basis. In cases that were not performed in the operating room, on completion of ECLS, patients were taken directly to the operating room or the cardiac surgery intensive care unit (ICU) according to the surgeon's preference. ECLS was performed through percutaneous cannulation or open cut-down and exposure of the femoral

vessels. The common femoral artery cannulas used ranged from 16F to 20F, and the common femoral vein cannulas ranged from 20F to 25F. For cases performed in the operating room, transesophageal echocardiography guidance was used for proper cannula placement. For patients placed on ECLS during cardiopulmonary arrest, transthoracic or transesophageal echocardiography was performed postprocedure in all cases. The same ECLS system was used in all cases (Maquet Cardiovascular LLC, Wayne, NJ). A centrifugal pump with a rotoflow biohead and 2-cone system was used to minimize hemolysis. A quadrox heparin-coated membrane oxygenator with integral heat exchanger was used.

The choice of ipsilateral limb perfusion strategy was based on the surgeon's preference. Hourly neurovascular checks were performed on all patients for limb ischemia monitoring. If the decision for expectant monitoring was made, then patients were directly transferred to the ICU. If the decision for PSFA cannulation was made, patients were taken to the operating room or the procedure was performed in the ICU. In both instances, percutaneous access to the SFA was obtained using ultrasound guidance with a micro-puncture needle. On obtaining antegrade access, a 4F sheath was exchanged over guidewire for a 7F sheath advanced into the SFA. It was connected to the arterial inflow cannula to restore antegrade flow into the lower extremity.

If the decision for open SFA cannulation was made, the procedure was always performed in the operating room. In patients in whom ECLS was established with percutaneous cannulation, a transverse incision was made below the percutaneous site and the SFA was exposed. Under direct visualization, tunneled antegrade access to the SFA was obtained and a 7F sheath was advanced over a guidewire using Seldinger technique. The groin incision was closed in typical fashion. In patients in whom ECLS was initiated using an open transverse incision for exposure of the femoral vessels, the SFA cannula was tunneled using the same incision for exposure of the vessel. In all cases, a 7F cannula was used for ipsilateral limb perfusion.

Monitoring Postextracorporeal Life Support

All patients were managed postoperatively in the ICU. The ECLS blood flow was adjusted to maintain a cardiac index greater than 2 L/m², with a mixed venous oxygen saturation goal greater than 60%. Ventilator settings were adjusted with oxygen flow titrated to maintain radial artery partial oxygen pressure greater than 100 mm Hg, with the goal of minimizing barotrauma especially in patients with primary pulmonary pathology. Carbon dioxide was maintained at 40 mm Hg or less. Anticoagulation was initiated to maintain partial thromboplastin time greater than 40 seconds initially and then accordingly increased to a goal of 60 to 70 seconds once good hemostasis was confirmed. The oxygenator was monitored closely for clots and immediately exchanged if perfusion pressures increased. Blood products were administered as required, typically to maintain platelet greater than 50,000 and hemoglobin greater than 8 g/dL. All patients were initially maintained on mechanical ventilation at bilevel settings, with goal peak airway pressure less than 25 cm H₂O and fraction of inspired oxygen of 0.4.

ECLS flows were optimized for perfusion, making sure that there was pulsatility on the arterial waveform. Inotropic support was initiated in patients in whom there was no left ventricular ejection. If this failed to generate arterial pulsatility or if the left ventricle was still severely dilated, a left ventricular vent (14F-18F) was placed through the right superior pulmonary vein via a right minithoracotomy approach. This was done in the operating room through a right anterior minithoracotomy approach. The blood return from the vent was connected to the venous drainage circuit of the ECLS. In some patients with primary coronary artery pathology, intra-aortic balloon pump counterpulsation was achieved through percutaneous placement via the contralateral femoral artery.

Patients were monitored on an hourly basis for limb ischemia. Baseline Doppler signals were recorded and marked for dorsalis pedis, posterior tibial, and popliteal flow bilaterally. Neurovascular checks were performed every hour, and the lower extremity was palpated hourly for signs of compartment syndrome. For any potential signs of limb ischemia, the cardiac surgical service and the vascular surgery service were involved in the management of the ischemic complication. Treatment for ischemic complications varied

TABLE 1. Demographic data and preoperative parameters

Characteristics	Total	No SFA	PSFA	Open SFA
No.	105	35	23	47
Age, y	50 ± 16	49.1 ± 18	49.6 ± 14	47.4 ± 16
Male	67 (63%)	24 (69%)	13 (57%)	30 (64%)
Body mass index	30.2 ± 8	30.1 ± 8	29.8 ± 8	29.9 ± 8
Transfer	72 (68%)	29 (83%)	15 (65%)	28 (59%)
Diabetes	24 (23%)	7 (20%)	6 (26%)	11 (23%)
Hypertension	39 (37%)	14 (40%)	8 (34%)	17 (36%)
Smoking	22 (21%)	7 (20%)	4 (17%)	11 (23%)
Cardiac arrest	32 (30%)	8 (23%)	5 (22%)	19 (40%)
ECMO location				
In-hospital ICU/floor	47 (45%)	15 (42%)	8 (35%)	24 (51%)
Operating room	49 (47%)	17 (49%)	13 (57%)	19 (40%)
Outside hospital	9 (9%)	3 (9%)	1 (4%)	5 (11%)
ECMO indications				

SFA, Superficial femoral artery; PSFA, percutaneous superficial femoral artery; ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit.

according to the cause and involved insertion of new SFA cannula, repositioning of the SFA cannula, exploration with repair of the SFA or profunda artery, 4-compartment fasciotomy, and below-knee amputation.

Patients were weaned off ECLS as soon as they showed signs of sustainable organ recovery. The decision was made on the basis of the clinical picture, echocardiographic evaluation, pulmonary status, and objective measures of adequate oxygen delivery. Patients who failed to wean from ECLS but otherwise recovered from cardiogenic shock were bridged to heart transplantation or ventricular assist device, or care was withdrawn in patients who were not candidates for transplantation or assist device therapy. After performing a bedside evaluation of the cardiopulmonary status on low ECLS flows with minimal settings on ECLS oxygenation and carbon dioxide clearance, suitable candidates were taken to the operating room for ECLS decannulation. In all cases, the femoral artery was exposed through an open cut-down. ECLS was weaned, and the common femoral artery was repaired primarily or with a pericardial patch. The SFA was primarily repaired. The femoral vein was primarily repaired if the cannulation was ipsilateral to the femoral artery cannulation. If contralateral, the venous cannula was removed and hemostasis was achieved with a large vertical mattress suture in the groin crease.

Statistics

All statistical analysis was performed using SPSS software (SPSS Inc, Chicago, Ill). Continuous variables are expressed as mean with 1 standard deviation and were compared using the Mann-Whitney *U* test. Categorical variables were expressed as percentages and analyzed using the Fisher exact test. The primary end point was limb ischemic complication requiring surgical intervention.

RESULTS

Patient demographics and preoperative risk factors in each group are shown in Table 1. Overall, there were no statistically significant differences among the 3 groups for demographic data. The majority of patients (88%, *n* = 92) were placed on ECLS for cardiac pathologies, with 12% (*n* = 13) for cardiopulmonary pathologies. The primary indication for ECLS in the entire group was primary cardiac failure, with acute myocardial infarction (*n* = 29, 27%) and cardiac arrhythmia (*n* = 18, 18%) being the primary causes of cardiogenic shock. Some 30% (*n* = 32) of the patients had at least 1 cardiac arrest event requiring cardiopulmonary resuscitation including

electrical defibrillation and chest compressions. Peripheral ECLS was used in 12 patients (11%) in the postcardiotomy setting. ECLS was initiated in the operating room in 49 patients (47%) and in the ICU/floor setting in 47 patients (45%), and 9 patients (9%) were transferred in from outside the hospital on an emergency basis.

Ipsilateral limb ischemia complications by each group are detailed in Figure 1. In total, there were 14 (13%) limb ischemic complications, with the highest rates occurring in the PSFA group (*n* = 6, 26%) and no SFA group (*n* = 7, 20%). In comparison with the open SFA group, there were significantly higher ipsilateral ischemic complications in the PSFA (*P* = .004) and no SFA (*P* = .02) groups. The management for limb ischemia varied, requiring femoral thromboembolectomy with artery repair (*n* = 4), lower-extremity fasciotomy (*n* = 4), SFA cannula revision (*n* = 3), and below-knee amputation (*n* = 1) (Figure 1). Two patients died in the ICU with limb ischemia before any surgical intervention could be undertaken.

Postoperative outcomes in the entire cohort and in each group are shown in Table 2. Overall mortality was 63% (*n* = 67). There were no significant differences among the 3 groups with regard to in-hospital/30-day mortality, hospital length of stay, or duration of ECLS support. A total of 22 patients (21%) were bridged to long-term mechanical assist device support, and 7 patients (6%) were bridged to successful heart transplantation from ECLS. To understand if limb ischemic complications were associated with any preoperative patient characteristics or affected patient outcomes, we assessed preoperative parameters and postoperative outcomes in patients who had limb ischemic complications versus those without (Table 3). The majority of patients with limb ischemia were male (*n* = 13, 93%; *P* = .01). Other parameters were similar between the 2 groups.

DISCUSSION

An ECLS strategy for end-stage cardiopulmonary pathologies is being used increasingly across the nation.^{1,4,7,14} At least the following factors make the application of this strategy attractive in situations of emergency and cardiopulmonary shock: (1) ECLS is relatively simple and time efficient to perform compared with more complex mechanical support systems; (2) ECLS can be performed in any hospital setting; (3) in situations of “bridge to decision,” ECLS is cost-effective compared with other mechanical support devices; (4) ECLS provides support for the heart and the lungs and therefore is a powerful tool in patients with severe cardiopulmonary compromise, unlike ventricular assist devices that provide cardiac support only; (5) ECLS enables right ventricular decompression, unlike left ventricular assist devices; (6) in patients with cardiogenic shock and end-organ malperfusion, ECLS is a great platform for patient resuscitation and recovery; (7) training surgeons and hospital staff, and resource allocation to perform and

FIGURE 1. Limb ischemia complications by SFA cannulation strategy are shown. SFA, Superficial femoral artery; PSFA, percutaneous superficial femoral artery; LE, lower extremity; ICU, intensive care unit.

care for patients who receive ECLS are relatively easier compared with assist device technologies; and (7) peripheral ECLS is minimally invasive, and complications can be dealt with greater ease compared with complications associated with devices in the chest. The markedly increased use of the ECLS platform is a reflection of the advantages it provides. But it is important to note that ECLS is not a permanent solution and is a bridge device: bridge to decision, bridge to transplant, bridge to ventricular assist systems, and bridge to recovery. In this context, it can be an ideal platform.

Given that ECLS platform is typically used in emergency situations and in patients with cardiopulmonary shock, it is critical to recognize that these patients have very poor reserve to tolerate technical complications. Therefore, any steps taken to prevent ECLS-related complications could have important implications for patient outcomes and their ability to be bridged to other permanent cardiopulmonary support systems.

TABLE 2. Postoperative outcomes for patients on peripheral arteriovenous extracorporeal membrane oxygenation

Characteristics	Total	No SFA	PSFA	Open SFA
No.	105	35	23	47
Duration on ECMO (h)	88.7 ± 120	87.7 ± 119	88.5 ± 121	89.2 ± 120
LOS (d)	18 ± 21	18 ± 21	18 ± 21	18 ± 21
IABP	22 (21%)	8 (23%)	4 (17%)	10 (21%)
Bridge to long-term assist device	22 (21%)	9 (26%)	2 (9%)	11 (23%)
Heart transplant	7 (6%)	2 (5%)	1 (4%)	4 (8%)
In-hospital 30-d mortality	67 (63%)	21 (60%)	14 (61%)	32 (68%)

SFA, Superficial femoral artery; PSFA, percutaneous superficial femoral artery; ECMO, extracorporeal membrane oxygenation; LOS, length of stay; IABP, intra-aortic balloon pump.

One such complication unique to peripheral ECLS is ipsilateral limb ischemia due to obstructed/decreased blood flow distal to the ECLS arterial cannula. In a study by Combes and colleagues⁶ looking at outcomes and long-term quality of life in patients on ECLS, femoral ECLS was associated with 20% limb ischemic complications. In another study by Doll and colleagues² looking at postcardiotomy ECLS patients, 54 of 219 patients had femoral arterial cannula placement ECLS. In the entire cohort, lower-limb ischemia was noted in 28 patients (13%), although the study did not specify the limb ischemia rate in the patients on ECLS with femoral arterial cannulation. Hei and colleagues¹⁵ looked at 5-year outcomes in 121 consecutive patients undergoing ECLS at a single institution and noted that limb ischemia was associated with increased in-hospital mortality on univariate analysis and multivariable logistic-regression analysis. These studies, in addition to other reports, signify the importance of preventing limb ischemic complications in patients on ECLS and the need for close monitoring for limb ischemia post-ECLS. Because the majority of these cases are performed in emergency situations with patients in cardiogenic shock, the majority of these patients are receiving high-dose and multiple inotropes and vasopressors, which exacerbate any malperfusion to the limbs.

At the Hospital of the University of Pennsylvania, as our techniques expanded and we increasingly used ECLS technology, we initially did not have any programmatic or algorithmic approach for addressing ipsilateral lower-limb perfusion in patients on femoral ECLS. The Hospital of the University of Pennsylvania is a tertiary care hospital, and many centers transferred patients to our ICU after they were placed on femoral ECLS at outside institutions. Therefore, variable peripheral ECLS with or without

TABLE 3. Patients' characteristics based on no limb ischemia versus limb ischemia

	No ischemia	Ischemia	P value
No.	91 (87%)	14 (13%)	
Male	54 (59%)	13 (93%)	.01
Age (y)	48.5 ± 16	48.1 ± 15	.5
CPR	29 (32%)	3 (21%)	.7
IABP	21 (23%)	1 (7%)	.3
Duration of support (h)	89 ± 120	88 ± 121	.02
BMI	30 ± 8	30 ± 8	.2
Renal failure (pre)	19 (21%)	4 (29%)	.5
Location of ECMO setup (OR/ICU/OSH)	44/40/7	5/7/2	.6

CPR, Cardiopulmonary resuscitation; IABP, intra-aortic balloon pump; BMI, body mass index; ECMO, extracorporeal membrane oxygenation; OR, operating room; ICU, intensive care unit; OSH, outside hospital.

ipsilateral limb perfusion strategies were used or patients placed on different femoral ECLS platforms were transferred for further management. In all cases, patients were monitored carefully for ipsilateral limb ischemia by hourly neurovascular examinations, and thus were expectantly managed. Anecdotally, we noticed that in patients without any distal limb perfusion strategy, such as an SFA cannula, there was increased limb ischemia. Therefore, we adopted a more aggressive and preventative approach by placing an ipsilateral SFA cannula for limb perfusion. This was done through PSFA cannula placement by ultrasound guidance or an open approach.

Our study shows that limb ischemia remains an important complication in peripheral ECLS cases (seen in 13% of cases), and a high index of suspicion must be maintained. This can be a catastrophic complication, requiring limb salvage procedures such as fasciotomy and lower-

extremity thromboembolectomy and arterial repair. One patient required a below-knee amputation. Up to 20% (n = 7) of patients who were expectantly managed without SFA cannulation developed limb ischemia, and this was treated surgically in all cases by placing an ipsilateral SFA cannula for limb salvage or the femoral ECLS cannulation was switched to the contralateral lower limb. In comparison, in patients who underwent SFA cannulation under direct visualization with an open cut-down, there was 1 ischemic complication. This patient developed bilateral lower-limb ischemia due to increasing high-dose inotropic and vasopressor requirements due to severe shock.

Of note, in patients who underwent preventative placement of an ipsilateral SFA cannula via percutaneous cannulation under ultrasound guidance, limb ischemic complications were still high (26%, n = 6). These complications were secondary to profunda femoris cannulation instead of SFA cannulation, posterior vessel wall injury, multiple attempts causing hematoma formation and vessel occlusion, and vessel thrombosis. These outcomes suggest that although initial ultrasound-guided access to the SFA/distal common femoral artery may have been successfully performed, guidewire placement into the distal SFA/guidance of the cannula into the SFA was not always successful and can be catastrophic. Therefore, to this effect over the past 2 years, we have changed our approach and have a programmatic and algorithmic strategy in place for the evaluation of ipsilateral limb perfusion (Figure 2).

In all patients on peripheral ECLS, whether they are transferred in from outside hospitals or for cases performed at our institution, we place an ipsilateral 7F SFA cannula. Percutaneous versus open SFA cannulation is performed on the basis of the surgeon's preference, but every patient

FIGURE 2. Current SFA cannulation algorithm in a patient on peripheral arteriovenous ECMO. ICU, Intensive care unit; SFA, superficial femoral artery.

undergoes formal lower-extremity angiography of the femoral vessels with distal run-off through a contrast dye injection via the SFA cannula to confirm proper placement (Figure 2). This is performed in the operating room, cardiac catheterization laboratory, or ICU setting with bedside fluoroscopy. Once we have angiographic confirmation of lower-limb perfusion via the SFA cannula, the patient is transferred to our ICU for further management. Since we have used this algorithmic approach, over the past year, we have not had any major limb ischemic complications requiring surgical reintervention in cases performed at the Hospital of the University of Pennsylvania. For outside ECLS transfers, in cases of ipsilateral lower-limb malperfusion, this strategy has enabled immediate detection and correction of the problem. We believe that the only downside to this strategy is the risk of contrast-induced nephropathy. Because the angiographic evaluation can be performed with as little as 5 to 10 mL of contrast agent, we believe that the risk of contrast nephropathy is very low. It will be important to monitor for this complication in the future.

Study Limitations

This is a retrospective analysis; therefore, interpretation of the data should be taken in this context. SFA cannulation strategy was based on the surgeon's preference and may be subject to operator variability. SFA cannulation techniques have evolved over the past decade at the Hospital of the University of Pennsylvania, especially routine SFA cannula angiography, and although there was a lot of overlap, this may have affected limb ischemia outcomes in particular groups.

CONCLUSIONS

Our study emphasizes that a high index of suspicion for limb ischemia must be maintained in patients undergoing femoral ECLS. Expectant monitoring without SFA cannulation-based lower-limb perfusion can be associated with a high lower-extremity intervention rate, including limb loss. This is especially important in patients on ECLS because these patients often are receiving multiple high-dose inotropes and pressors to treat cardiogenic shock. Because of poor or no pulsatility in the arterial waveform in the lower-extremity arteries in these patients, neurovascular examinations can be misleading and less objective. Therefore, we advocate for absolute confirmation of ipsilateral lower-limb perfusion. This may be performed by placement of a chimney graft to the common femoral artery and then arterial cannulation of the graft for ECLS. In cases of direct femoral arterial cannulation for ECLS, which is the preferred technique at most centers, placement of a SFA cannula can minimize limb ischemic complications. Open cut-down with SFA cannulation remains a safe approach. PSFA cannulation without angiographic confirmation is associated with high limb ischemia complications. Therefore, regardless of percutaneous or open SFA cannulation

approaches, angiographic evaluation through the SFA cannula is highly recommended for absolute confirmation of lower-limb perfusion.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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References

1. Zangrillo A, Landoni G, Biondi-Zoccai G, Greco M, Greco T, Frati G, et al. A meta-analysis of complications and mortality of extracorporeal membrane oxygenation. *Crit Care Resusc.* 2013;15:172-8.
2. Doll N, Kiaii B, Borger M, Bucieris J, Krämer K, Schmitt DV, et al. Five-year results of 219 consecutive patients treated with extracorporeal membrane oxygenation for refractory postoperative cardiogenic shock. *Ann Thorac Surg.* 2004;77:151-7.
3. Ganslmeier PA, Philipp L, Rupprecht C, Diez M, Arlt T, Mueller K, et al. Percutaneous cannulation for extracorporeal life support. *Thorac Cardiovasc Surg.* 2011;59:103-7.
4. Rousse A, Al-Attar N, Alkhoder S, Radu C, Raffoul R, Alshammari M, et al. Outcomes of percutaneous femoral cannulation for venoarterial extracorporeal membrane oxygenation support. *E Heart J.* 2012;1:111-4.
5. Ko W, Lin C-Y, Chen RJ, Wang S-S, Lin F-Y, Chen Y-S. Extracorporeal membrane oxygenation support for adult postcardiotomy cardiogenic shock. *Ann Thorac Surg.* 2002;73:538-45.
6. Combes A, Leprince P, Luyt C-E, Bonnet N, Trouillet J-L, Leger P, et al. Outcomes and long-term quality of life of patients supported by extracorporeal membrane oxygenation for refractory cardiogenic shock. *Crit Care Med.* 2008;36:1404-11.
7. Smedira NG, Moazami N, Golding CM, McCarthy PM, Apperson-Hansen C, Blackstone E, et al. Clinical experience with 202 adults receiving extracorporeal membrane oxygenation for cardiac failure: survival at five years. *J Thorac Cardiovasc Surg.* 2001;122:92-102.
8. Schwarz B, Mair P, Margreiter J, Pomaroli A, Hoermann C, Bonatti J, et al. Experience with percutaneous venoarterial cardiopulmonary bypass for emergency circulatory support. *Crit Care Med.* 2003;31:758-64.
9. Gander JW, Fisher JC, Reichstein AR, Gross ER, Aspelund G, Middlesworth W, et al. Limb ischemia after common femoral artery cannulation for venoarterial extracorporeal membrane oxygenation: an unresolved problem. *J Pediatr Surg.* 2010;45:2136-40.
10. Bisdas T, Beutel G, Warnecke G, Hoeper MM, Kuehn C, Haverich A, et al. Vascular complications in patients undergoing femoral cannulation for extracorporeal membrane oxygenation support. *Ann Thorac Surg.* 2011;92:626-31.
11. Cheng R, Hachamovitch R, Kittleson M, Patel J, Arabia F, Moriguchi J, et al. Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: a meta-analysis of 1866 adult patients. *Ann Thorac Surg.* 2014;97:610-6.
12. Aziz F, Brehm CE, El-Banyosy A, Han DC, Atinip RG, Reed AB. Arterial complications in patients undergoing extracorporeal membrane oxygenation via femoral cannulation. *Ann Vasc Surg.* 2014;28:178-83.
13. Foley PJ, Morris RJ, Woo EY, Acker MA, Wang GJ, Fairman RM, et al. Limb ischemia during femoral cannulation for cardiopulmonary support. *J Vasc Surg.* 2010;52:850-3.
14. Lubnow M, Philipp A, Foltan M, Enger T, Lunz D, Bein T, et al. Technical complications during venovenous extracorporeal membrane oxygenation and their relevance predicting a system-exchange-retrospective analysis of 265 Cases. *PLoS One.* 2014;9:e112316.
15. Hei F, Lou S, Li J, Yu K, Liu J, Feng Z. Five-year results of 121 consecutive patients treated with extracorporeal membrane oxygenation at Fu Wai Hospital. *Artif Organs.* 2011;35:572-8.
16. Russo CF, Cannata A, Vitali E, Lanfranco M. Prevention of limb ischemia and edema during peripheral venoarterial extracorporeal membrane oxygenation in adults. *J Card Surg.* 2009;24:185-7.

17. Lamb KM, Hirose H, Cavarocchi NC. Preparation and technical considerations for percutaneous cannulation for veno-arterial extracorporeal membrane oxygenation. *J Card Surg.* 2013;28:190-2.
18. Rao AS, Pellegrini RV, Spezioli G, Marone LK. A novel percutaneous solution to limb ischemia due to arterial occlusion from a femoral artery ECMO cannula. *J Endovasc Ther.* 2010;17:51-4.
19. Benassi F, Vezzani A, Viganali L, Gherli Y. Ultrasound guided femoral cannulation and percutaneous perfusion of the distal limb for VA ECMO. *J Card Surg.* 2014;29:427-9.

Discussion

Dr F. Beyersdorf (*Freiburg, Germany*). This study is important because more patients are being treated with ECLS. You have shown the problems with limb ischemia, but there are other potential problems, for example, hypoperfusion of the coronary arteries and cerebral hypoperfusion. Cardiac surgeons usually are aware of this problem, but ECLS is used more and more by other kinds of physicians, and it is important to point to all potential complications.

First, you stated that the choice of limb perfusion (no limb perfusion, percutaneous or open antegrade limb perfusion) was left to the choice of the surgeon. After completion of your study, is it routine now in your center to use antegrade limb reperfusion in all ECLS cases?

Second, you mentioned in your presentation that you have used chimney grafts to perfuse the limb. My experience is that chimney grafts might lead to severe hyperperfusion of the limb. Did you see this as well?

The third question is related to your observation that there were no differences in mortality between the 2 perfusion groups. However, did you see in the survivors more amputations or more fasciotomies than in the nonsurvivors?

Dr Vallabhajosyula. The answer to the first question is that, yes, we now routinely in perform antegrade limb perfusion in every patient. This was actually the point of the study, and, to some extent, this is us hanging our dirty laundry. What I think we really learned is that when the patient comes in as a transfer to a tertiary care center or when we perform echocardiography, to say that, oh, you check perfusion and you think you see pulses and that's good enough, I don't think works. So in our experience, every patient now gets an SFA cannula and a 7F SFA cannula. But we also found that performing a PSFA cannulation without angiographic confirmation is dangerous.

Dr Beyersdorf. That's exactly our experience as well. You had the highest rate of limb ischemia in the percutaneous approach, and this is understandable, because often you just don't perfuse the right vessel.

Dr Vallabhajosyula. So we always do the percutaneous cannulation. If it's done in the catheter laboratory, obviously we used to routinely shoot an angiogram, but

sometimes it's done with ultrasound guidance. Even if you guide the wire down and you think you're in the right spot, I think it's not uncommon to end up in the profunda, and I think that was one of our biggest learning lessons. So we have changed, as I mentioned, in our practice. No matter how and where the extracorporeal membrane oxygenation (ECMO) is done, every patient gets an SFA cannula and angiographic confirmation. We don't do chimney grafts. I know that other institutions do use chimney grafts, and our exact reason for not doing it is the hyperperfusion concern.

Dr Beyersdorf. Do you see any difference in fasciotomies between survivors and nonsurvivors?

Dr Vallabhajosyula. In the survivors versus nonsurvivors, yes, we did. In the patient who survived, there were no fasciotomies. Eleven of the 14 patients who ended up having limb ischemia died.

Dr T. Grodzki (*Szczecin, Poland*).

This is an important article because this is a real clinical problem. The question is why did you select SFA for cannulation instead of doing a same size bypass to the main femoral artery? It is quite simple, particularly in the open fashion, because sometimes the anatomic variations in the SFA are so strange that you are not sure about the proper perfusion of the limb.

Dr Vallabhajosyula. You mean sewing a bypass graft to the side of the common femoral distal artery?

Dr Grodzki. To the same femoral artery you placed the cannula.

Dr Vallabhajosyula. If we do an open cut-down ECMO or we have done a percutaneous ECMO, we try to go as close to the cannulation site as possible, and then under angiographic confirmation, we put in a 7F cannula that we have tunneled. We have not attempted a bypass graft.

Dr R. J. M. Klautz (*Leiden, The Netherlands*). On the basis of these problems and neurologic outcomes, we switched to routinely use the subclavian artery with a bypass graft. In approximately 100 patients, we have not seen any limb ischemia, and the hyperperfusion syndrome of the arm occurred in only 1 patient. Actually, this has been beneficial. It is cumbersome, but it gives much better outcomes, and if you routinely use that, all surgeons can do that.

Dr Vallabhajosyula. I think that's a great strategy, but a lot of our patients are transferred in on ECMO or we do it on an emergency basis with arrest, and I think that strategy is not something that's feasible in those conditions. It's also hard to justify to transfer the cannulas to the axillary site once you have already committed to a femoral cannulation.